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Power Quality Improvement by Solar Photo-voltaic/Wind Energy Integrated System Using Unified Power Quality Conditioner

Sarita Samal, Prakash Kumar Hota
Department of Electrical Engineering, Veer Surendra Sai University of Technology, Burla, Odisha, India

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ABSTRACT

The real problems in diminution of power quality occurs due to the rapid growth of nonlinear load are leads to sudden decrease of source voltage for a few seconds i.e sag, swell, harmonics in source and load current, voltage unbalance etc. All these problems can be compensated by using Unified Power Quality Controller (UPQC) and the operation of UPQC depends upon the available voltage across capacitor present in dc link. If the capacitor voltage is maintained constant then it gives satisfactory performance. The proposed research is basically on designing of Photo Voltaic (PV) /Wind energy fed to the dc link capacitor of UPQC so as to maintain proper voltage across it and operate the UPQC for power quality analysis. The said model is simulated in Matlab and results are verified by using FFT analysis.The proposed PV/ Wind energy-UPQC is design in Matlab simulation for reduction of voltage sag, swell, interruption of voltage, harmonics in load current and compensation of active and reactive power.

Corresponding Author:

Sarita Samal,
Department of Electrical Engineering,
Veer Surendra Sai University of Technology,
Burla, odisha, India
Email: saritaruchy@gmail.com

1. INTRODUCTION

The use of electricity is increasing very rapidly so the necessity of renewable energy based source is required for interconnection to the distribution network. The main drawbacks of the renewable sources are the power generation is not continuous and it is season based. To overcome these disadvantages numbers of renewable sources are interconnected [1], [2]. The compensation principle and different control strategies of the UPQC in detail and performance of UPQC is examined by considering, a diode rectifier feeding an RL load (non linear load) that acts as a source of harmonics [3]. The theory, modeling and application of a unified power quality conditioner has been described by [4]. The coordinated and integrated control of solar PV generators with the maximum power point tracking (MPPT) control and battery storage control to provide voltage, frequency (V-f) and P-Q control, respectively, with PV generator and battery storage support to an islanded Microgrid [5]. Femia *et al* [6] have developed a scheme for maximum power point tracking (MPPT) of solar PV system using perturb and observe method. Gaeid *et al* [7] have design a unified power quality conditioner (UPQC) including a series and a shunt active power filter (APF) to compensate harmonics in both the distorted supply voltage and nonlinear load current. In the series APF control scheme, a proportional-integral (PI) controller, meanwhile a PI controller and are designed in the shunt APF control scheme to relieve harmonic currents produced by nonlinear loads. Basu *et al* [8] have made a comparative evaluation of two models of UPQC for suitable interface to enhance power quality. Montero *et al* [9] have developed number of method for shunt active power filters used in three-phase system. Lee *et al* [10] described the control techniques of series active power filters compensating for source voltage unbalance and

current harmonics. An efficient voltage sag recognition procedure for a dynamic voltage restorer has been developed by Fitzer *et al* [11]. The simulation and experimental design of shunt active power filter for harmonics and reactive power compensation have been described by Jain *et al* [12]. The advantage of the above method is that it maintains the dc link voltage constant and when there is no sun light Wind energy can provide necessary power to the UPQC for its operation. The major disadvantage of UPQC is that it cannot compensate the voltage interruption but proposed method can perform all the function as UPQC can and also compensate the voltage interruption.

2. PV/ WIND ENERGY INTEGRATED UPQC CIRCUIT AND ITS FUNCTIONS

In the proposed method the design and development of the proposed PV/Wind energy-UPQC system. By using instantaneous *d-q* control theory techniques along with PI and hysteresis band controller, the mitigation of voltage sag and swell under different balance and unbalanced load conditions are simulated. The use of a PV array and Wind energy for retaining fixed DC link voltage is another distinguishing feature of the PV/Wind energy -UPQC system. With these functions, the proposed method is suitable for connecting at PCC. The proposed configuration with UPQC is shown in Figure 1. Where voltage interruption reimbursement and active power injection to the Point of Common Coupling (PCC) in addition to the other regular UPQC operation can be achieved.

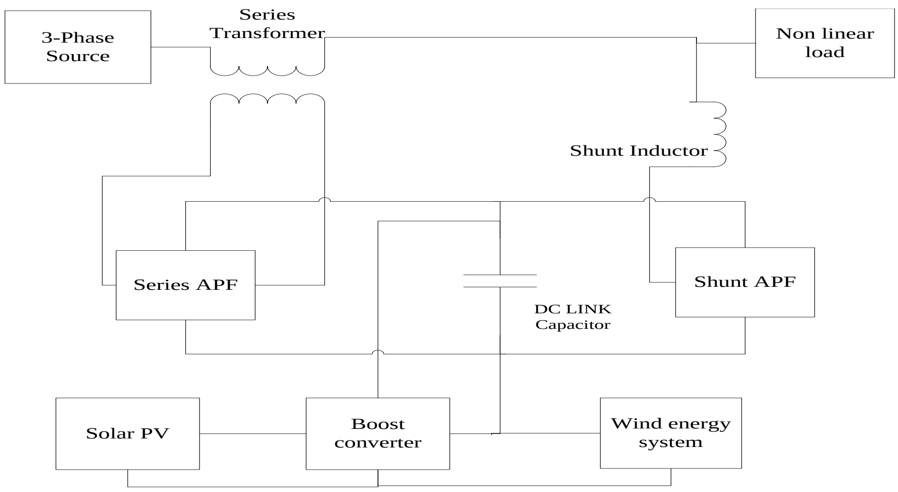


Figure 1. Basic Block diagram for PV/ Wind energy - UPQC system

2.1. Modeling of Solar PV

Solar photo-voltaic system works on the principle that when a light energy falls on solar cell it converts it to electrical energy. The Figure 2 shows here is an equivalent model of solar PV system representing single diode model. It consist of a photo current I_{ph} which depends on temperature and irradiation, the series resistance represent the internal resistance due to which current I flows and the shunt resistance describe the flow of I_{sh} which is a leakage current [13].

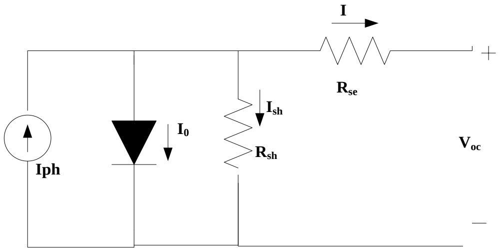


Figure 2. Solar cell single diode model

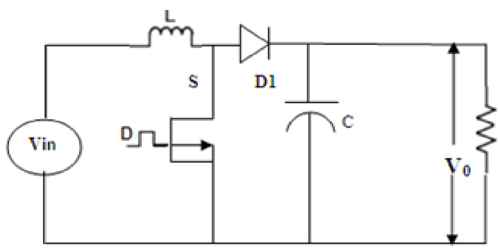


Figure 3. Basic circuit for Boost converter

The load current, photo current and other Equation.

$$I = I_{Ph} - I_0 - I_{sh} \quad (1)$$

$$I_{Ph} = [I_{sc} + K_i(T_k - T)] \times \frac{G}{1000} \quad (2)$$

$$I_{RS} = \frac{I_{sc}}{[exp(q \times V_{OC}/N_S \times k \times A \times T) - 1]} \quad (3)$$

$$I_0 = I_{RS}\left[\frac{T}{T_r}\right]^3 exp\left[\frac{q \times E_{go}}{Ak}\left\{\frac{1}{T_r} - \frac{1}{T}\right\}\right] \quad (4)$$

$$I_{PV} = N_P \times I_{Ph} - N_P \times I_0\left[\exp\left\{\frac{q \times V_{PV} + I_{PV}R_{se}}{N_s \times AkT}\right\} - 1\right] \quad (5)$$

Where
I_{PV}-Diode photo current
I_O-Reverse saturation current of diode
V_{pv}-Diode voltage
V_{oc} - Open circuit voltage
R_{se}-Series Resistance
R_{sh}-Shunt resistance

2.2. MPPT

The solar panel efficiency is increased by the use MPP technique. The MPPT is the application of maximum power transfer theorem which says that the load will receive maximum power when the source impedance is equal to load impedance. The MPPT is a device that extracts highest power from the solar cell and changes the duty ratio of boost converter so as to match the load impedance to the source**.**

2.3. P and O MPPT

There are many method of MPPT out of which P & O technique is mostly used by the researcher due to its simplicity and cost effective. This method works on an algorithm that first PV panel terminal voltage and current are calculated and related value of power is measured denoted by P (k-1). The detail algorithm is shown in below flow chart figure 4 which describes the algorithm for designing the MPP system using P&O by Matlab simulation [14], [15].

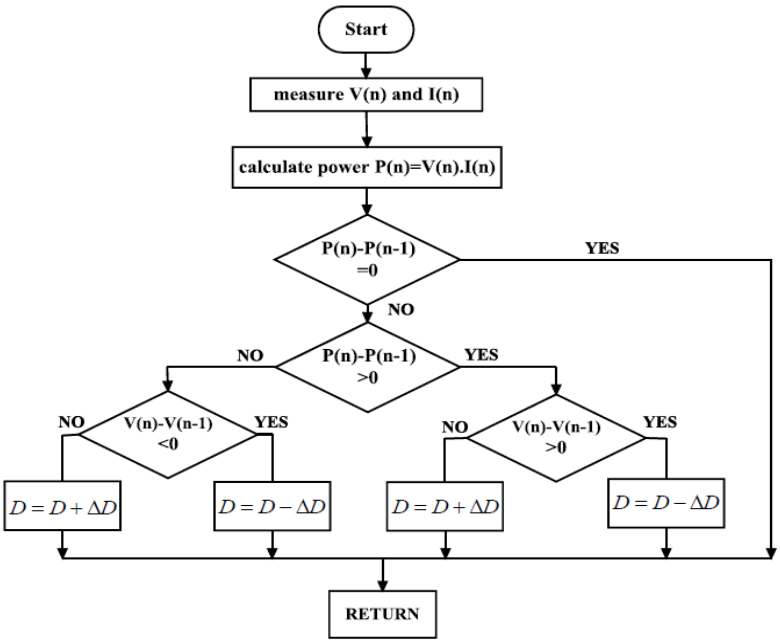


Figure 4. Flowchart of P & O MPPT algorithm

2.4. DC/DC Step up Converter

A step up DC/DC converter is a boost converter which increases the solar voltage to desired output voltage as required by load. The configuration is shown in Figure 4 which consists of an inductor *L*, switch *S*, diode D_1, capacitor *C* for filter, load resistance R and DC input voltage V_{in}. When the switch S is turned ON by using switching pulse the boost inductor stores the energy fed from the input voltage source and during this time the load current is maintain by the charged capacitor so that the load current should be continuous [16]. During the switch off period the input voltage and the stored inductor voltage will appear across the load hence the load voltage is increased, so the load voltage is depends upon weather switch S in ON or OFF and this is depends upon the duty ratio D.Science the switch conducts with a duty ratio *D* and then the output DC voltage is given by Equation 6.

$$\frac{V_0}{V_S} = \frac{1}{1-D} \tag{6}$$

The minimum value of duty cycle Dmin and maximum value of duty cycle Dmax used for a lossless boost converter is given by the following Equations.

$$D_{max} = 1 - \frac{V_{in-min}}{V_o} \times \eta \tag{7}$$

Where, D_{max} is the maximum duty ratio required to keep the converter in Continuous Conduction Mode (CCM)

$$D_{min} = 1 - \frac{V_{in\_max}}{V_o} \times \eta \tag{8}$$

Where, D_{min} is the minimum duty cycle required to keep the converter in CCM

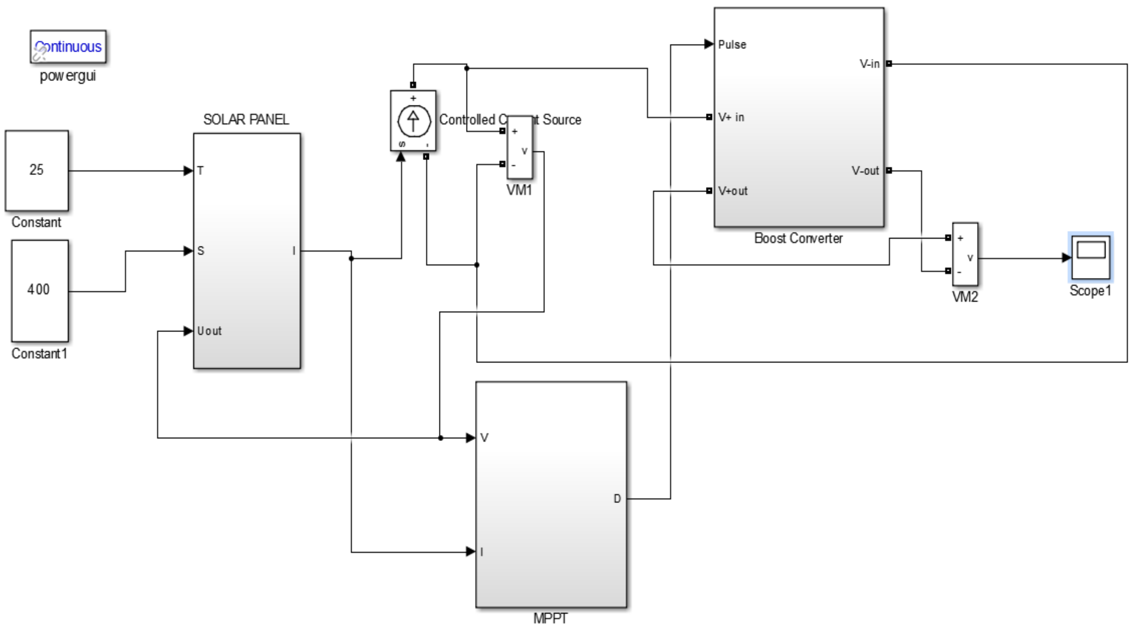


Figure 5. Simulation of Solar PV with MPPT and Boost converter

2.5. Matlab/Simulation of PV System

In general the efficiency of a PV unit is extremely low; therefore it is essential to operate it at the peak power point so that the highest power can be provided to the load irrespective of continuously varying environmental conditions. This improved power makes it well again for the use of the solar PV unit. A DC/DC converter which is located next to the PV unit extracts maximum power by matching the impedance of the circuit to the impedance of the PV unit Impedance matching is possible by changing the duty ratio of the boost converter. The simulation of solar PV with P&O MPPT and Boost converter is shown in Figure 5.

The P-V and I-V characteristic of PV module is shown in Figure 7 and Figure 6.

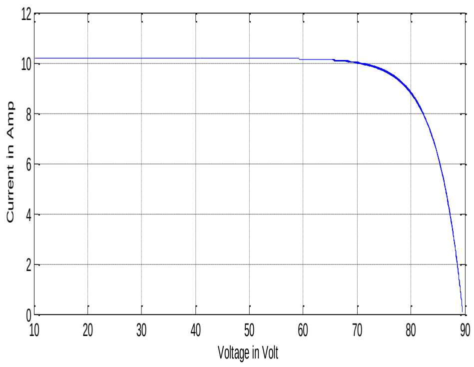


Figure 6. I-V Characteristics of PV module

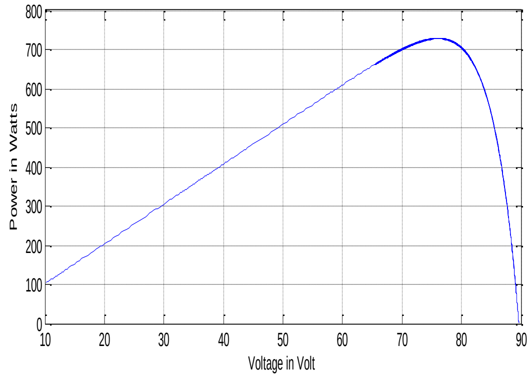


Figure 7. P-V Characteristics of PV module

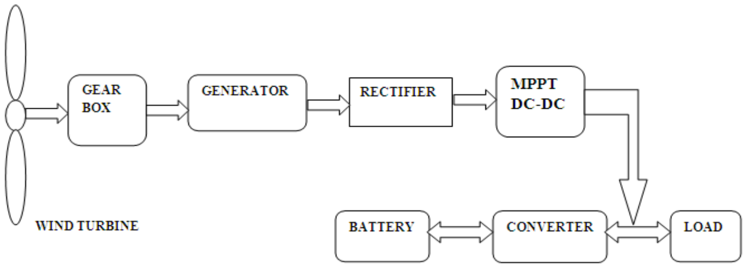


Figure 8. Wind energy system block diagram

3. WIND ENERGY SYSTEM

The diagram shown in Figure 8 is the basic wind energy conversion system model. The wind kinetic energy first converted to rotational motion and by the use of gear box it is matches the speed of turbine and generator. The function of generator is to convert the mechanical energy of turbine to electrical energy. A rectifier is used to convert the AC voltage to DC and a battery is connected in such a way that it can charged both the way i.e a bidirectional converter is used to charged the battery [17].

3.1. Modeling of Wind Turbines

The kinetic energy of wind is converted to rotational motion i.e wind power to mechanical power conversion is done with the help of wind turbine blade in contact with wind speed. So different Equation are given for power generation from wind [18], [19].

$$Pm = \frac{1}{2}\pi\rho Cp(\lambda,\beta)R^2V^3 \tag{9}$$

Where, P_M– Mechanical power, ρ–Air density, β –Pitch angle, R–Blade Radius–Speed of the wind λ is the tip-speed ratio, given by $\lambda = \Omega R/ V$. Where, Ω - Rotor speed of rotation (in rad/sec) and C_P can be expressed as the function of the tip-speed ratio (λ)

$$C_p = \frac{1}{2}\left(\frac{116}{\lambda_1} - 0.4\beta - 5\right) exp^{\frac{-165}{\lambda_1}} \tag{10}$$

$$\lambda_1 = \left(\frac{1}{\frac{1}{\lambda+0.089} - \frac{0.035}{\beta^3+1}}\right) \tag{11}$$

Where, C_P –Power coefficient of turbine and λ_1–Any constant

3.2. Permanent Magnet Synchronous Generator (PMSG)

In case of (PMSG) permanent magnet synchronous generator the magnetic field is stationary and the flux is produce by permanent magnet not by electromagnet, so a separate supply is not required for creation of magnetic field and the field flux remain constant. Another advantage of PMSG is that there is no requirement of slip ring. All other construction remains same as that of normal synchronous generator [20], [21]. The e.m.f induced in a synchronous generator.

$$E = 4.44\text{Ø}_m t\ f \tag{12}$$

Where, f - Frequency in Hz, Φm - maximum flux in Wb and t- Number of turns.The simulation of wind turbine with generator and rectifier is shown in Figure 9.

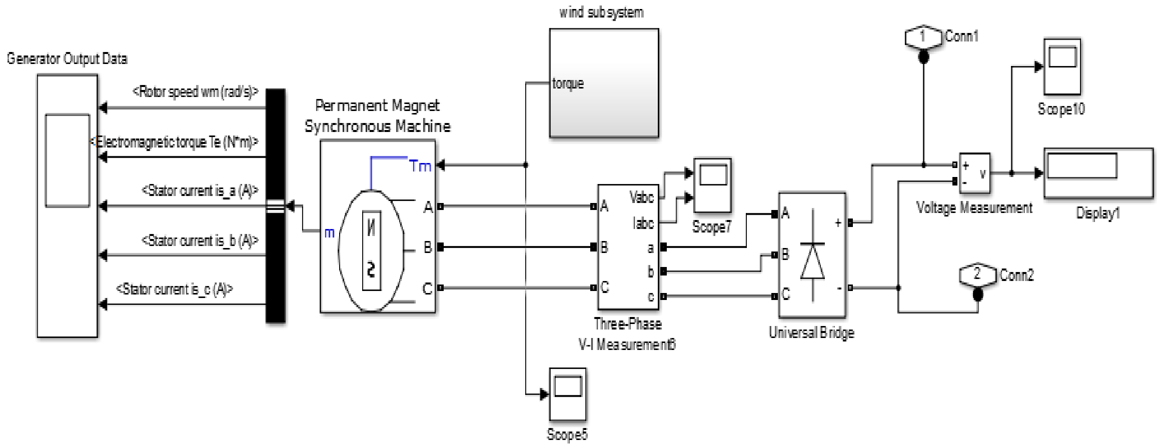


Figure 9. Simulation of wind system with PMSG and Rectifier

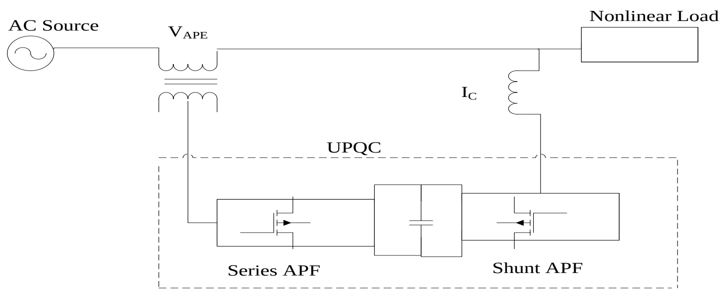


Figure 10. Block diagram of UPQC

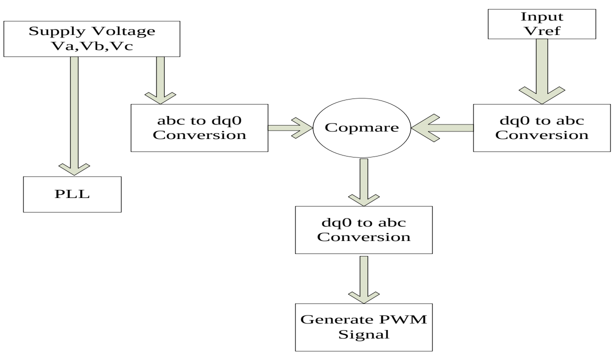


Figure 11. Control scheme of series Active Filter

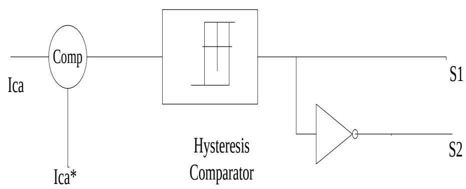


Figure 12. Principle of hysteresis current controller

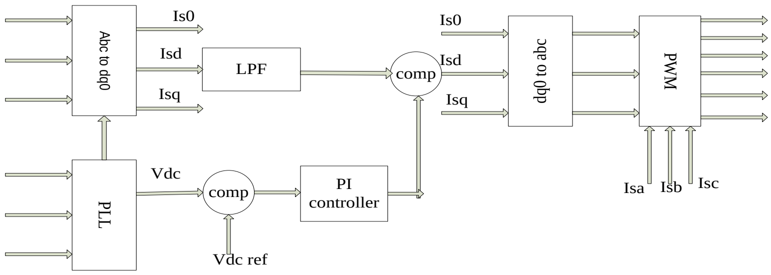


Figure 13. Control scheme of Shunt Active Power Filter

4. CONTROL STRATEGIES OF THE UPQC SYSTEM

There are several control strategies available to find out the reference values of the voltage and the current of UPQC. The Figure 10 shows the block diagram for control strategies of UPQC system. The concept of instantaneous active power (*p*) and reactive power (*q*) and its application in shunt filter reference current generation, the synchronous reference frame theory, the fuzzy logic control (FLC) for the control of UPQC method are some of the above mentioned control strategies. Based on the above discussion, *d-q* theory with hysteresis current control mode is suitable for parallel mode operation of UPQC system and *d-q* theory with PWM voltage control mode is suitable for interruption mode operation. The hysteresis control method is simple to implement and it has enhanced system stability, increased reliability and mitigates power quality problems.

4.1. Control Scheme of Series Active Filter

The block diagram for series APF control scheme is shown in Figure 11 where Park's transformation method is used for generation of unit vector signal. The actual voltage and the reference are converted to *dq0* from *abc* coordinates and both are compared in *dq0* reference frame. After the comparison both are again converted to *abc* reference frame. From PLL (phase locked loop) Ø can be generated which is required for Park's transformation and inverse Park's transformation. The switching pulses required for VSI conduction are generated from the comparison of selected output voltage (Vc*) with the sensed series APF output voltage (Vc) in a hysteresis voltage controller.

4.2. Control Scheme for Shunt Active Power Filter

The shunt (APF) is normally connected in parallel to the system which indicates the harmonics content. To eliminate the harmonics, the equal amount of harmonic compensating current is injected in opposite phase w.r.t the harmonic current. The control scheme shown in Figure 13 includes the transfer of source current from *a-b-c* to *d-q* frame. In nonlinear load the source current includes both oscillating as well as dc component. The dc component is only positive sequence component but the oscillating component includes positive, negative and zero sequence components. To maintain the DC link voltage this active filter will absorb some active power from the power system. The shunt active filter eliminates the harmonics component present in the source current & make the source current wave form pure sinusoidal by acting as a current controlled voltage source inverter.

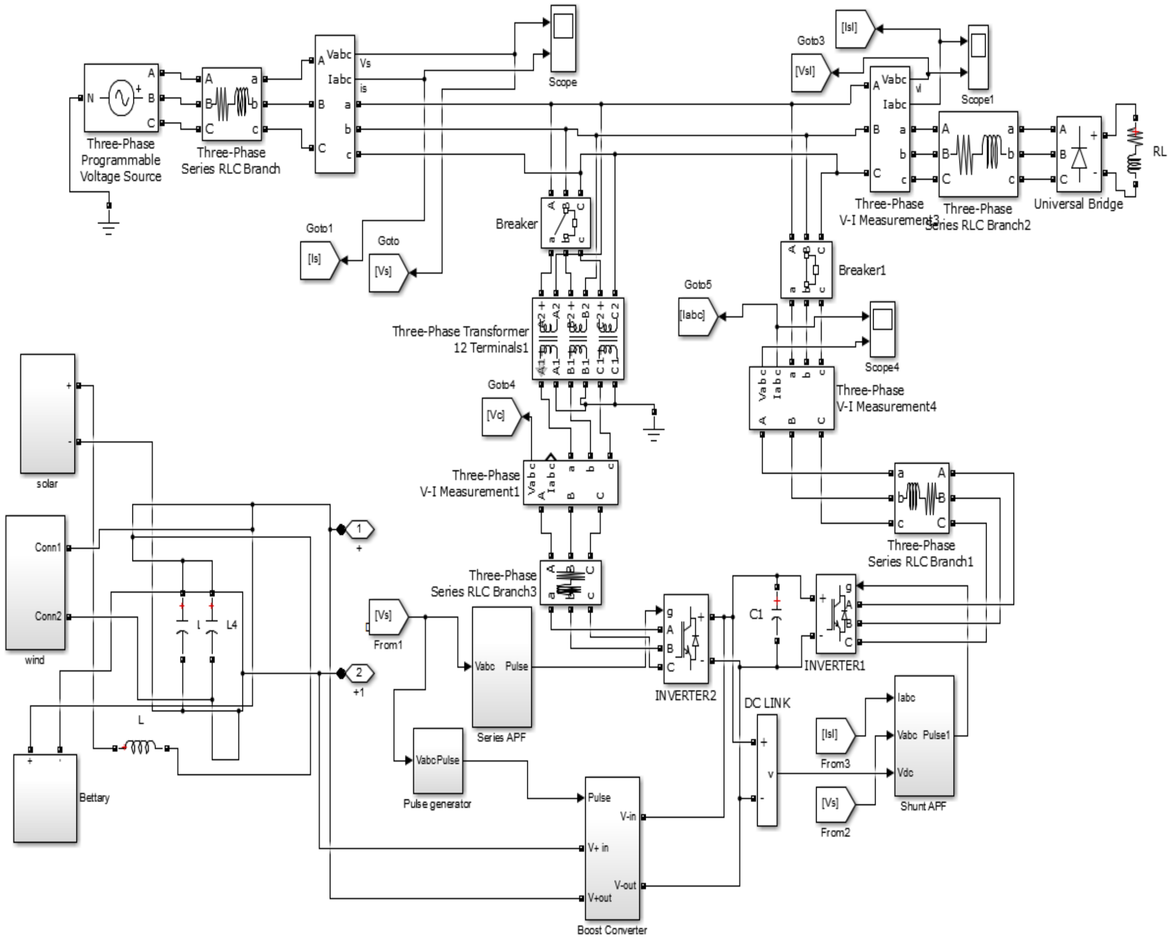
4.4. Design of Shunt Apf

a. DC link capacitor: The active and reactive power flow to the system is provided by the link capacitor when it is required.
b. Voltage source inverter: The electronics device which converts direct current to alternating current when PWM signal is given to the gates of its IGBT or GTO etc. Here the main function of the VSI is to compensate the source current harmonics present by injecting the equal and opposite compensating current to the system.
c. Hysteresis Current Controller: Hysteresis current controller shown in Figure 12 generates PWM signal by comparing the reference signal w.r.t to the actual signal the figure below shows the generation of PWM signal by comparing the two current signals.

5. SIMULINK MODEL OF SOLAR PV/WIND ENERGY-UPQC SYSTEM

5.1. Result Analysis

The simulink models of PV/Wind energy-UPQC are simulated in Matlab which is shown in Figure 14 which consist of series APF, shunt APF, solar PV, wind energy and boost converter. The simulation result shown in Figure 15 is without series filter where voltage sag is clearly shown from 0.1sec. to 0.3sec. When the series active filter injects voltage from 0.1sec.to 0.3sec shown in Figure 16, the load voltage is compensated to actual value as shown in Figure 17. The Figure 18 shows the simulation result load current before compensation and Figure 19 shows the harmonics content i.e. 16.6% by using FFT analysis. When the shunt active filter injects current from 0.1sec.to 0.4sec as shown in Figure 20, the load current harmonics is reduce to2.33% as shown in the FFT analysis in Figure 22 for which the load current is nearly sinusoidal as shown in Figure 21.



Figur 14. Simulation of PV/Wind –UPQC system

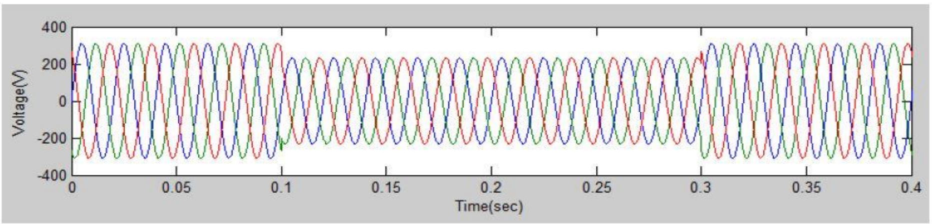


Figure 15. Load Voltage without SAF

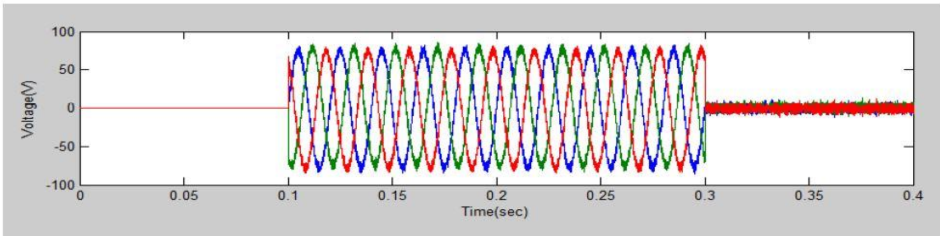


Figure 16. Injected Voltage

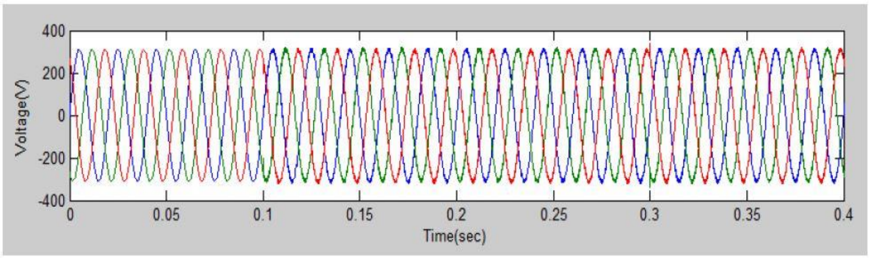


Figure 17. Load Voltage with SAF

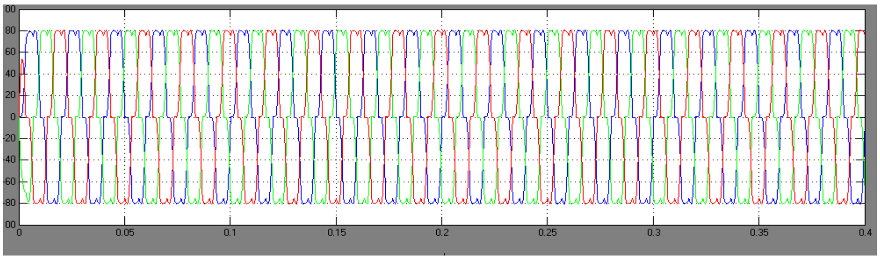
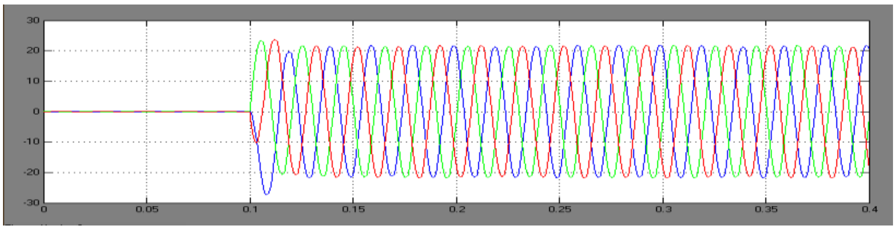


Figure 18. Load current before compensation



Figur 19. Current Injected by shunt active filter

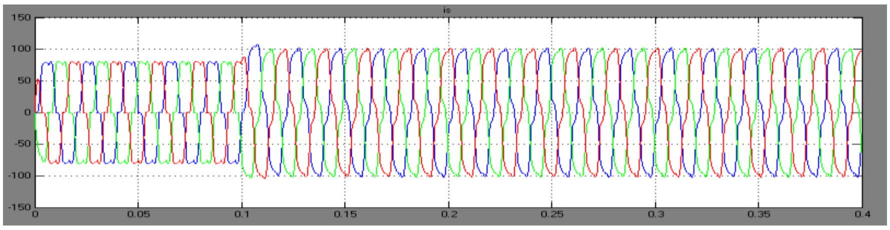


Figure 20. Load current with shunt APF

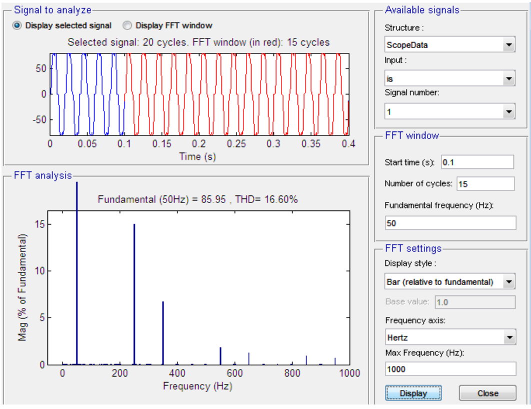


Figure 21. Harmonics analysis without shunt APF

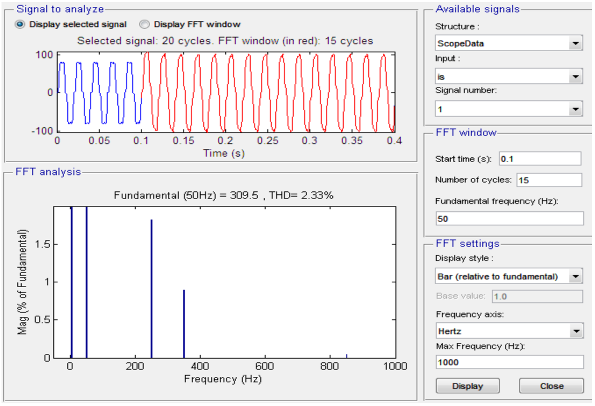


Figure 22. Harmonics analysis with shunt APF

6. CONCLUSION

The advantage of Photo Voltaic / Wind energy System is to retain a constant voltage of 700 volts across the DC-Link capacitor. In this work the solar PV with boost converter output is obtaining 700V and Wind energy with boost converter output is also 700Vand simulation of PV/ Wind energy -UPQC maintains constant voltage of 700V when Sag, Swell and Interruption occur. It also reduces the harmonics content to 2.33% if any nonlinear load is associated. Hence the proposed scheme can regulate active and reactive power injection to the grid and compensate voltage interruption in addition to the other usual operation of UPQC.

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BIOGRAPHIES OF AUTHORS

Sarita Samal was born in 1981 in India. She was received her B.Tech (Hons) in electrical engineering from Berhampur University in 2003 and her M.Tech., in power system engineering from VSSUT Burla, in 2006. She is currently pursuing her Ph.D. in VSSUT Burla. Her current research interests include power quality improvement and application of power electronics with non-conventional energy sources.

Prakash Kumar Hota was born in 1963 in India. He has graduated in Electrical and Electronics Engineering from the National Institute of Technology (NIT), Tiruchirapalli, India in 1985, received his M.Tech in Industrial Power Control & Electric Drives in 1992 from Sambalpur University, India and Ph.D in Electrical Engineering from Jadavpur University, Kolkata, India in 1999. Currently, he is a Professor of Electrical Engineering and Dean of Centre for Distance and Continuing Education (CDCE) at Veer Surendra Sai University of Technology (VSSUT), Burla, India. His research interests include Economic Emission Load Dispatch, Hydrothermal Scheduling, Hybrid Power Generation Systems, Power Quality and Soft Computing applications to different Power System Problems in Deregulated Environment